Limitations of Numerical Methods in Analysis of Contact Stresses of Joints in Mechanical Engineering

Tomasz Podolski, Marian Dudziak

***Abstract*—The paper presents the comparative analysis of spigot joint modeling in two commercial programs. The modeling method of joint and the results of the computer simulation are presented. The comparison of the obtained results allows to give design directions and tendency of further works.**

***Index Terms*—Contact analysis, contact stresses, joint modeling**

I. Introduction

MODERN machines and appliances require a high quality of manufacturing. On a quality of the whole machine essential influence has a quality of its constituent components connections. Therefore analysis of joints improvement analysis is essential. It became possible thanks to numerical methods development which enabled more accurate evaluation of geometrical parameters and computer numerical methods, and these methods enable evaluate a quality of designed machine with high accuracy already on designing stage.

In case of connecting elements the important quality parameter is contact stress. Owing to the fact that these elements sometimes transfer high mechanical loads, their contact stresses values may approach allowable stresses. The classical calculation methods are restricted to a general evaluation of forces which are applied to the selected surface. Unfortunately, such calculations are burdened with a big mistake.

Newer approach to analysis of contact stresses is usage of numerical methods. Classical methods are based on the Hertz theory with numerous modifications. These modifications aim at removing of the Hertz classical model limitations. Nevertheless, referring to literature analysis, in case of inner contact problem of two rollers with nearly equal radii there is essential discrepancy between the Hertz model and the models of Reish, Schtaerman, Dobychin, and Hafner [1] - [4].

Therefore as a purposeful there was recognized analysis of numerical algorithms contained in commercial software enabling contact problems solving [5] - [7]. For this purpose there were used two programs: I-DEAS V11 of the company EDS and ABAQUS V6.9 of the company Dassault Systemes. These programs were used for the sake of their possibility (availability) of complicated geometry creating and having FEM module with a wide base of finite elements and mesh generating effective generation.

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Tomasz Podolski is with the Chair of Basics of Machine Design, Poznan University of Technology, 60-965 Poznan, Poland (corresponding author, phone: +48-61-665-2042; fax: +48-61-665-2074; e-mail: tomasz.podolski@put.poznan.pl).

Marian Dudziak is with the Chair of Basics of Machine Design, Poznan University of Technology, 60-965 Poznan, Poland (e-mail: marian.dudziak@put.poznan.pl).

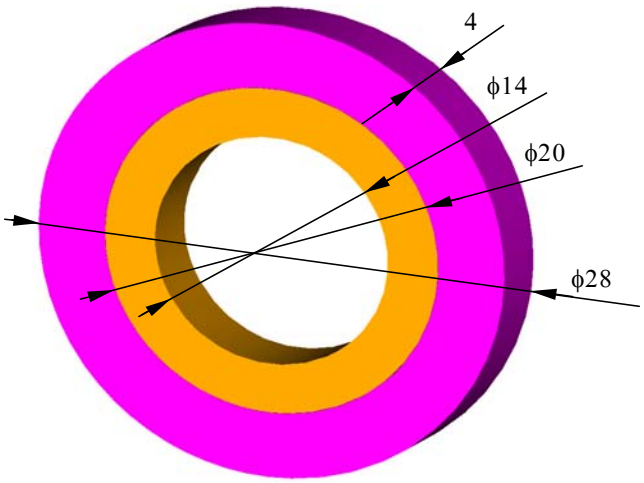

Fig. 1. Geometrical dimensions of rings (mm)

The aim of this elaboration was comparison of above mentioned programs algorithms used for solving contact problems comprising the full range of connections (from close up to clearance fits). For this purpose there were developed models of the same geometrical features, the same loads and restraints, and the same material characteristics. It turned out to be impossible to define an equal mesh distribution of finite elements. It is caused by different requirements referring to generation of contact finite elements. For I-DEAS program the best results can be obtained when on contact surfaces are generated the same quantities of finite elements. In case of ABAQUS program there is recommended compressing of mesh on slave surface and master surface should have the smaller quantity of nodes.

There were analyzed a connection consisting of two rings (fig. 1). The dimension of inner diameter of outer ring were changed within the range ϕ20 ± 0,05mm with the step of 0,01mm. This way there obtained one by one 11 computational models comprising close and clearance fitted connections. The outer ring had taken away all degrees of freedom, and the inner one had taken away shift along Z axis.

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II. Modeling of Connection in I-DEAS Program

In I-DEAS program to the inner surface of the smaller ring applied the static load of 2000(N) directed vertically down (each 1000(N) to two different surfaces as a traction on surface, total force). As the contact parameters were used default values. However sometimes it proved that there were necessary to enlarge parameters of the penalty factor normal from 10 up to 10000, and the Tangential from 1 up to 100. There were enlarged also the maximal quantity of Contact status loop iteration from 20 up to 30. The mesh was locally refined around the mating surfaces. Models of outer and inner rings had 6000 elements and 7700 nodes each.

Below there are presented the results of numerical analyses which were conducted in I-DEAS program.

Significant matter is also distribution of above values.

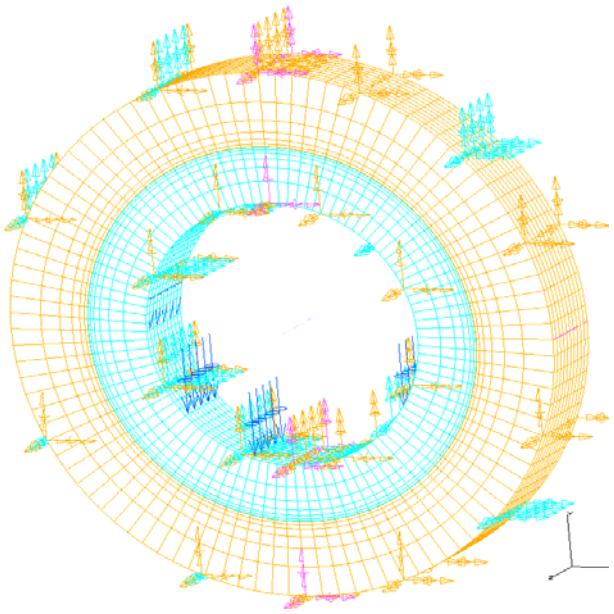

Fig. 2. Computational model in I-DEAS program

TABLE I
Collection the Maximal Malues of: Reduced Stress According to the Huber-Mises Hypothesis, Distortion Energy, Displacement, Restraint Reaction, Contact Pressures and Contact Stresses.

dimm.	Huber-Mises	displacem.	react. forc.	contact press.
(mm)	(MPa)	(mm)	(N)	(MPa)
20,05	153,28	0,03675	16,50	64,04
20,04	149,59	0,03131	14,82	60,71
20,03	142,91	0,02567	12,67	53,42
20,02	132,19	0,01980	10,87	44,79
20,01	112,13	0,01349	9,81	41,04
20	66,55	0,00576	10,10	39,34
19,99	422,59	0,01161	108,01	409,62
19,98	422,59	0,01161	108,01	409,62
19,97	843,49	0,02231	215,61	817,64
19,96	843,49	0,02231	215,61	817,64
19,95	1053,52	0,02770	269,28	1021,07

Below there are presented the results of simulation of stresses reduced according to the Huber – Mises and contact pressures of chosen models with the ring diameters: ϕ20,05, ϕ 20,00 and ϕ 19,95 (clearance, sliding and close connections).

The result analysis shows a possibility of using I-DEAS computational system in contact connections analysis. From the table 1 data analysis it could be noticed that in a range of close connections occur a discrete characteristic and for clearance connections a continuous characteristic.

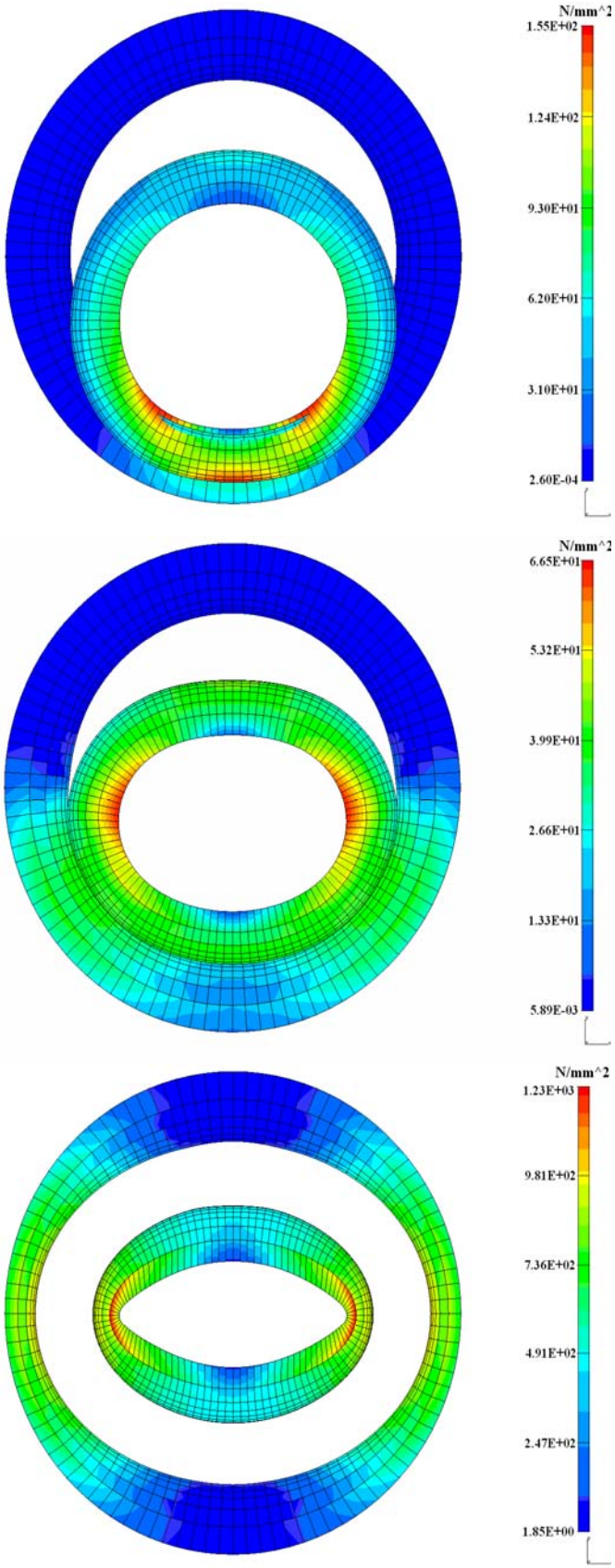

Fig. 3. Values of reduced stress for clearance, sliding and close connections

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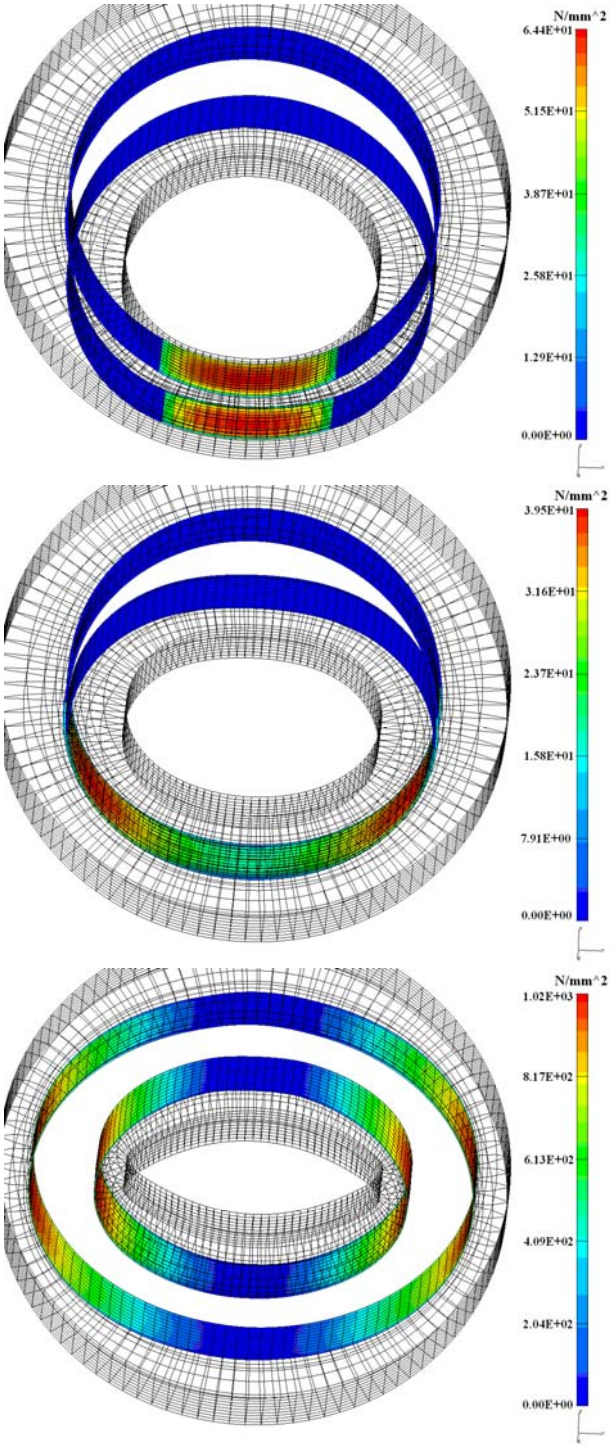

Fig. 4. Values of contact pressures for clearance, sliding and close connections

III. Modeling of Connection in ABAQUS Program

In ABAQUS program a load was applied as a surface traction with the magnitude 11.3682 (N/mm^2), which totally loads a model surface with the force amounts 2000N. For a contact definition was made an assumption: the tangential behavior - Frictionless, the normal behavior – default, the Pressure - Overclosure – "Hard" contact. The finite sliding formula with the surface to surface digitization method was accepted for an interaction between mating surfaces. Other parameters were assumed as default values.

The internal ring model had 6000 elements and 7700 nodes, the external ring had 7104 elements and 9324 nodes.

There has been presented the simulation values of reduced stresses according to the Huber-Mises hypothesis and also contact pressures for chosen models with the ring diameters: ϕ20,00 and ϕ19,95 (sliding and close

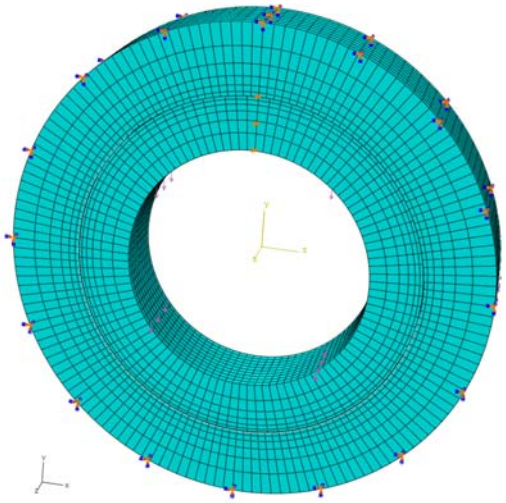

Fig. 5. Computational model in ABAQUS program

TABLE II
THE MAXIMAL VALUES OF: REDUCED STRESSES ACCORDING TO THE HUBER-MISES HYPOTHESIS, DISPLACEMENTS, RESTRAINT REACTIONS AND CONTACT PRESSURES..

dim.	huber-mises	displacem.	react. forc.	contact press.
(mm)	(N/mm^2)	(mm)	(N)	(N/mm^2)
20,00	73,3	0,00820	6,75	28,91
19,99	138,2	0,00506	11,95	50,64
19,98	259,3	0,00979	20,11	85,1
19,97	380,6	0,01451	28,27	119,6
19,96	501,8	0,01923	36,45	154,2
19,95	623,2	0,02394	44,64	188,7

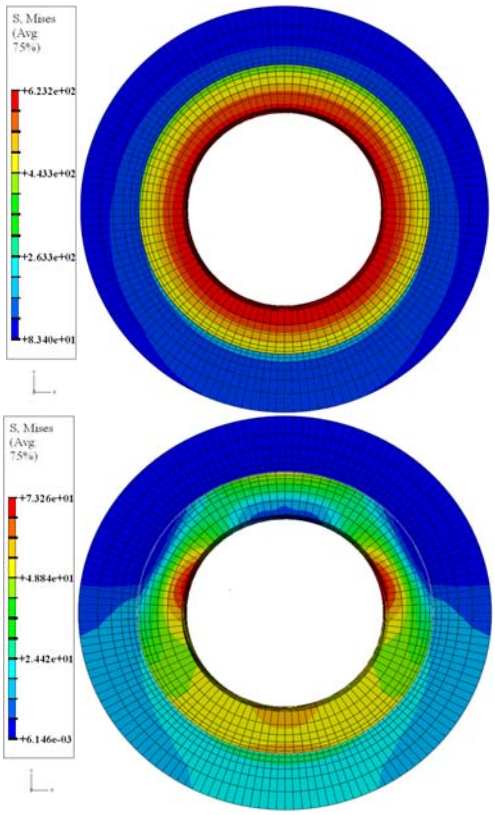

Fig. 6. Values of reduced stresses for close and sliding connections

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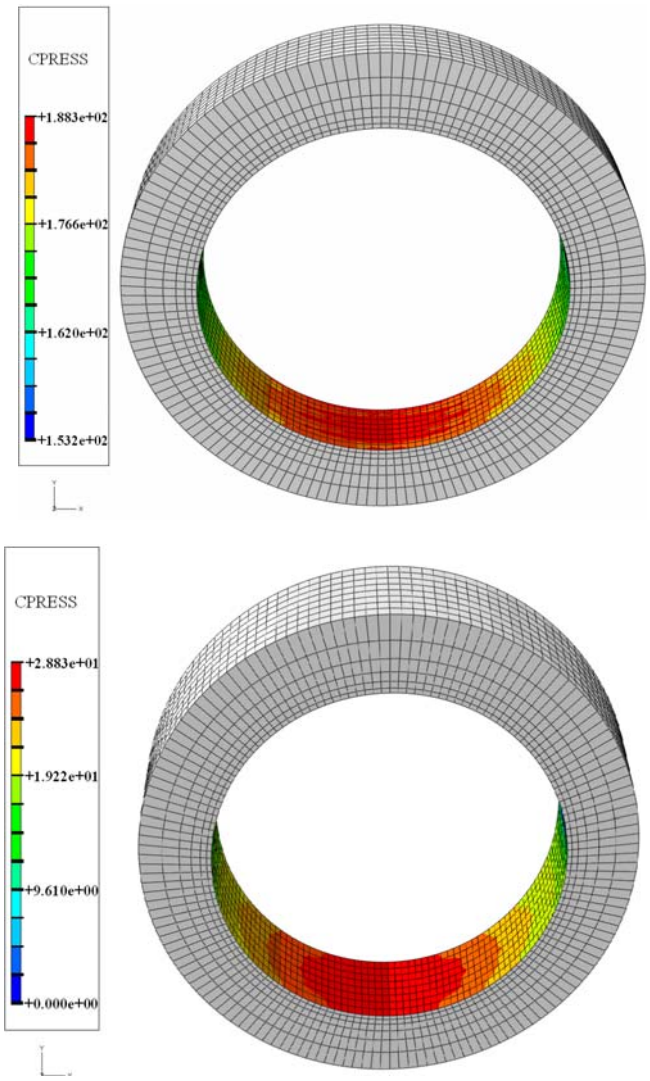

Fig. 7. Values of contact pressures for close and sliding connections

Computational simulations show potential using for ABAQUS computational system in analysis of contact connections with interference. It could be noted from the table 2 that in a range of close connections occur a continuous characteristic. It couldn't manage to obtain results of clearance connection computations (solver didn't get a convergence of an iteration cycle). Contact parameters changing didn't help, neither numerical computation algorithms changing.

IV. Comparison of the Results

Underneath there are presented the results of numerical computations.

It should be mentioned that there were a lot of troubles during a comparison of two different applications for engineering computations. The I-DEAS program is a versatile application. The numerical computation module is worse than in ABAQUS program. However, more effective is the generation and modification of finite element mesh tools. The algorithms of contact elements generation are simpler. However, understanding the limitations of these algorithms (identically quantities of finite elements on cooperation surfaces) allows to obtain the correct results of computation, especially in a range of the clearance connections.

The ABAQUS program is dedicated to a spread range of numerical simulations. Its solver is acknowledged as one of the best. Lack of obtaining results in a range of clearance connection could be surprised.

The analysis of results shows on convergence of both programs only in case of the sliding connection. A difference in the results of reduced stresses is about 10%, in computations of contact pressures is 27%. The computation results of close connections in I-DEAS program cannot be

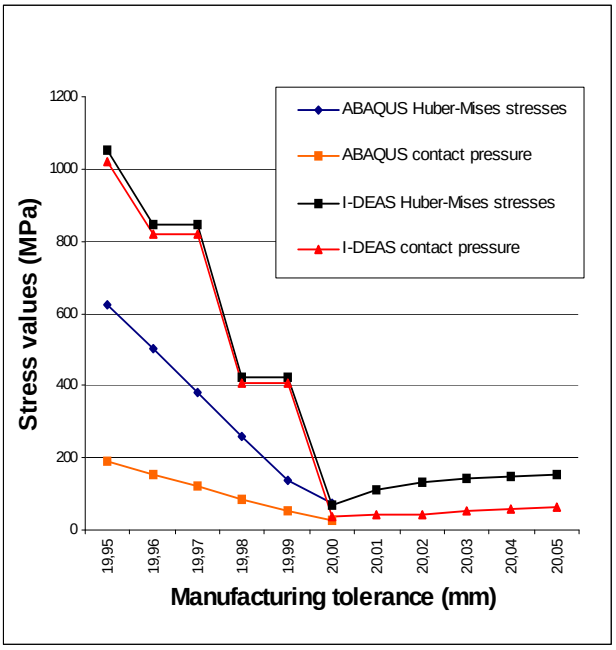

Fig. 8. Influence of manufacturing tolerance on contact stresses

treated as adequate (inappropriate character of strains and lack of characteristic linearity). During observation of numerical algorithms efficiency, the more effective for close connections analysis is ABAQUS program, while for clearance connections I-DEAS program. In order to confirm these conclusions it should be built more complex models and further analyze contact algorithms.

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